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Guidance and Navigation Technology

I'm here to tell you about our Guidance and Navigation Technology programs. I'd like to start by telling you about two active programs, then discuss some new ideas.

The first is called Global Positioning Experiments, or GPX, aimed at solving the GPS jamming threat. GPS jammers are an insidious threat. The GPS signal is very weak and easy to jam. Jammers can be built out of cheap, easy-to-get components, and are so small that it's difficult to find them. Bottom line is any adversary could deploy large numbers of GPS jammers quite effectively, and we'd never know it until the conflict began.

We are solving the problem of GPS jamming by using airborne pseudo-satellites (or "pseudolites") which provide high power GPS signals to overpower jammers. You can think of a pseudolite system as being a miniature GPS constellation. Four pseudolites are required for a full navigation solution, just like four GPS satellites are required today. The concept is that the airborne pseudolites would find their own position from GPS satellites, even in the presence of jamming. They do this through a state-of-the-art beamforming antenna and signal processor that decrease the effects of jamming. Then they transmit a GPS-like signal to the ground at much higher power and at closer range than the satellites can. This signal overwhelms the jammer and allows the multitude of users to ignore the jamming and continue to navigate.

At DARPATech 2000 I reported that we had successfully shown accurate navigation via pseudolites in a series of field tests by Rockwell-Collins in November 1999. We also showed in April 2000 that the pseudolites were powerful enough to overcome jamming.

Since these first two field demonstrations, we have focused our efforts on making the pseudolite itself immune to jamming. Remember, the pseudolite platform has to navigate using the GPS satellites. To do this, we are using a seven element antenna array and a state-of-the-art digital beamformer to reject jamming signals at the pseudolite. MIT Lincoln Laboratory and Rockwell Collins have built a system to give 40-55 dB of jamming immunity, using a combination of space and time adaptive processing. The system has been tested in mini-anechoic chambers, at the Air Force GPS Wavefront Simulator at Wright-Patterson AFB, and in some rudimentary field tests, and has met its goal. This April we integrated the system on a Falcon aircraft and tested the entire system in a full scale anechoic chamber. The results met the goals of the program.

In September we will fly the Falcon in a live jamming field at Holloman AFB, New Mexico. We will be testing to see if it successfully rejects jammers, and to see if it keep a highly accurate pseudolite signal while the jammers are on. We expect it will succeed quite well, based on our previous testing.

The GPX program will end in the summer of 2003, when we have scheduled a pair of field demonstrations to show a full system of 4 airborne pseudolites providing accurate navigation to a variety of users, including precision weapons, while being jammed. In these demonstrations we will also be showing a shaped beam transmission antenna for the pseudolite signal, and a command and control system that controls the pseudolite network transmissions.

The pseudolite approach to GPS jamming mitigation is a unique one. It puts out a stronger signal than the satellites, and because it doesn't need to wait for a space launch, it is available much sooner than the high power GPS satellites. It also does not require expensive hardware modifications to the thousands of DoD users out there. In short, it has many advantages, and we are working to find transition partners in the DoD and industry at the same time that we demonstrate solutions to all the technical issues. If you are interested in working with DARPA to transition pseudolites, see me afterwards.

The second program is building an inexpensive, small inertial navigation system (or INS). The idea is to use Micro-ElectroMechanical System technology (or MEMS), which can produce low-cost mechanical systems using manufacturing techniques similar to the electronics industry. By making the INS very small and cheap, a wide variety of military systems can use it.

We envision a wide variety of applications for MEMS INS. Today and in the future, U.S. soldiers and vehicles will be equipped with GPS receivers for geo-location. But GPS doesn't work when you're inside buildings, under dense foliage or under water. When this happens, the MEMS INS can provide navigation until GPS signals are restored, and also help with re-acquiring the GPS signals. Being small and low cost, a MEMS INS can support the guidance function in air-to-surface and surface-to-surface munitions. A MEMS INS could support pointing and orientation for artillery and targeting equipment. We suspect that when we achieve our goal of a tactical grade INS costing $1200, the military and civil applications will increase enormously, much like they have for GPS.

The three contractors developing MEMS-based inertial navigation systems in the program are Litton Guidance and Control Systems, Draper Laboratory and Kearfott Guidance and Navigation Corporation. All three contractors are working towards tough performance, power and volume goals. The accuracy goals are 1-10 degrees/hour gyro drift rate and 0.5 mg accelerometer bias. The size goal is 10 cubic inches, and the power consumption should be less than 3 Watts. These contractors are delivering their final inertial measurement units (IMUs) and gyros this summer.

The most difficult part of building a MEMS-based inertial measurement unit, or IMU, is the gyroscope. An IMU consists of accelerometers and gyroscopes. While MEMS accelerometers are relatively mature, MEMS gyroscopes are much harder to build, and have been the pacing technology item in this program. The gyroscope designs developed by the three contractors in the program are depicted here.

So how are we doing? Draper Laboratory will produce an IMU that meets the size and weight goals of the program. Kearfott's IMU will be a little larger, at 17 cubic inches. The use of ASICs in place of the discrete circuit boards would shrink the IMU to 10 cubic inches. Litton will be delivering a gyroscope only.

The IMUs and gyro are going through government testing by the US Air Force test squadron at Holloman Air Force Base, New Mexico, starting with the Draper IMU. The units will be tested on rate tables and centrifuges under a variety of temperature and vibration conditions to see how well they meet the performance goals. When government lab testing is complete, the IMUs and gyro will be available for testing by potential customers. If you are interested in testing them or using them in an application, please contact me.

The MEMS INS program has shown that smaller, efficient, MEMS-based IMUs can be produced. The performance, as measured by the gyroscope error, will range from 1 degree/hour to 20 degrees/hour, depending on the environment. This accomplishment has laid the ground for a number of other military programs interested in affordable IMUs.

As a variation on the MEMS theme, we started an effort one year ago to produce a meso-sized gyroscope, but using the same fabrication tools as the MEMS approach. The idea was originated at Boeing Space Systems and the Jet Propulsion Lab, and initially sponsored by DARPA's Defense Science Office. The gyroscope is about 10 times the size of the MEMS gyros, but since the MEMS fabrication process errors are about the same, the expected relative error is at least 10 times better. Results after a year of work by Boeing and JPL indicate a gyroscope with 0.4 degree/hour error. We are beginning a two-year effort to incorporate this gyroscope into an IMU, which should be complete in 2004. We are seeking partners interested in an IMU with better than 1 degree/hour error. If you are, come see me.

Finally, we are also looking for new ideas in navigation and guidance. The MEMS INS solution, while great for the so-called tactical user satisfied by 1 degree/hour accuracy, does not solve everyone's problem. Most aircraft, ships, spacecraft, and many missiles require better accuracy, and almost any tactical user will buy as accurate a system as he can afford. As indicated by the meso-gyro effort, we are always interested in ideas to produce affordable, small, robust navigation solutions to serve higher precision DoD needs. If you have ideas on how to do this, come see me.

Also, while a strong motivation for the MEMS INS program was for man-portable navigation, it is clear that a MEMS IMU alone is not a solution for a soldier. Soldiers' missions last hours or days, during which an INS will drift wildly. Integrated sensor systems are clearly required. While GPS is clearly a wonderful sensor for the soldier, it does not work in buildings, dense foliage, or urban environments. If you have ideas for extremely small, low-powered human-based navigation approaches that are suitable for these GPS-challenged environments, please see me.